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A RELATION BETWEEN KNOCK-LIMITED OR PREIGNITION-LIMITED AIR-FUEL RATIO AT LEAN MIXTURES AND FUEL-AIR RATIO AT RICH MIXTURES

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A RELATION BETWEEN KNOCK-LIMITED OR PREIGNITION-LIMITED AIR-FUEL RATIO AT LEAN MIXTURES AND FUEL-AIR RATIO AT RICH MIXTURES

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SUMMARY

A derivation is presented to show that, if the air-fuel ratio at lean mixtures is plotted agaist the fuel-air ratio at rich mixtures for identical values of the knock-limited (or preignition-limited) indicated mean effective pressure on each side of the minimum indicated-mean-effective-pressure point, a straight line should result. This linear relation is checked for several cases of knock-limited and preignition-limited CFR engine data. The correlation obtained indicates that the influential variables controlling the knock-limited (or preignition-limited) performance of a fuel in the lean-mixture and rich-mixture branches of the performance curve are related.

INTRODUCTION

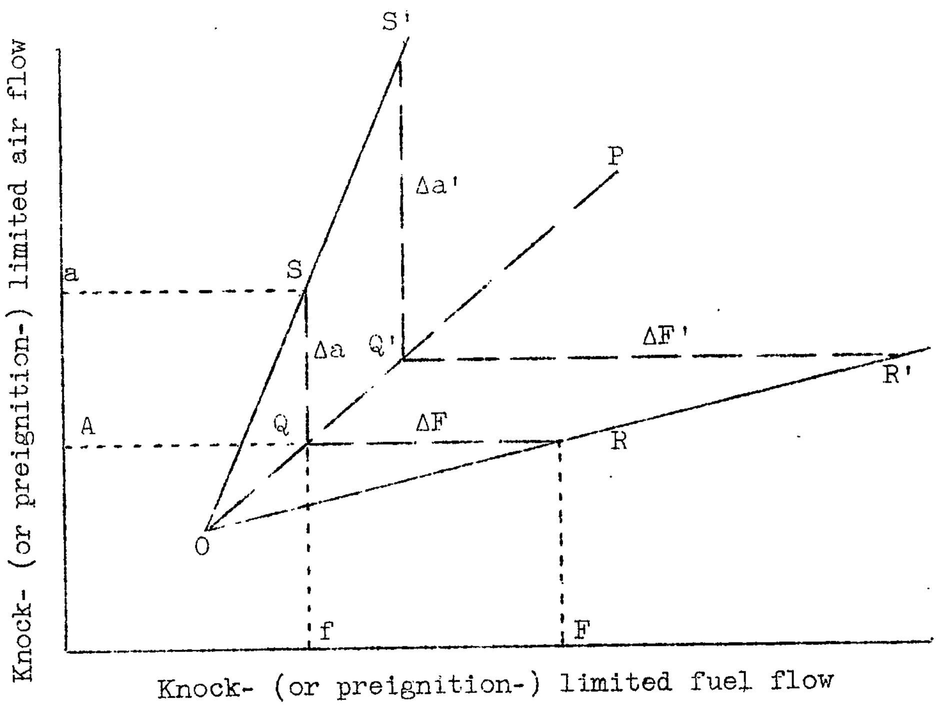
Considerable experimentation has been conducted by American and foreign engineering laboratories to determine the effects of fuel-air ratio on the knock-limited performance of various fuels. The determination of what causes fuel-air ratio to be important, however, is extremely difficult, and the results from engine tests, even with fuels of standardized composition, are by no means consistent. Under special circumstances the apparent effects of fuel-air ratio are influenced by the exhaust pressure, by the mechanical condition of the engine, by the mode and time of fuel injection (intake or cylinder), and by the severity of the engine conditions. Certain general effects of fuel-air ratio in relation to other variables have nevertheless been observed. For instance, both the "best economy" spark advance (reference 1) and the mean effective gas temperature (reference 2) are influenced by fuel-air ratio.

Curves other than the customary ones showing the variation of power with fuel-air ratio have been applied to both knock-limited and preignition-limited data with some sucess. Under some circumstances curves of knock-limited air flow against fuel flow for supercharged engines yield two straight intersecting lines, one for the lean-mixture region and one for the rich-mixture region. Charts in reference 3, obtained by plotting preignition-limited air flow against fuel flow, also show two intersecting lines. A certain degree of correlation, therefore, apparently exists between lean-mixture and rich-mixture knock-limited (or preignition-limited) performance.

A lean-rich correlation based on the assumption that plotting knock-limited or preignition-limited air flow against fuel flow gives two intersecting straight lines is described herein. The method is checked for several cases of knock-limited and preignition-limited data. The work was conducted at the Cleveland laboratory of the NACA.

ANALYSIS

Consider a chart showing the variation of either knock-limited or preignition-limited air flow with fuel flow upon which two intersecting straight lines OS' and OR' are obtained. (The triangular area enclosed by the boundary S'OR' is the knocking or preigniting region.)



Construct through the intersection a line OP of constant fuel-air ratio and pick any two points Q and Q' on this line. Draw the lines of constant fuel flow QS and Q'S' and of constant air flow QR and Q'R'. Let a and f represent air flow and fuel flow, respectively, above and to the left of the line OP (considered to be the lean-mixture region) and let A and F represent air flow and fuel flow below and to the right of OP (considered to be the rich-mixture region). The fuel-air ratio of the line OP (approximately the stoichiometric mixture ratio) can then be represented as:

$$f/A = \alpha \tag{1}$$

When the length of the lines QR and QS (with or without primes) are represented by ΔF and Δa, by proportion

$$\frac{\Delta a}{\Delta a'} = \frac{OQ}{OQ'} = \frac{\Delta F}{\Delta F'}$$

Rearranging the first and last members of the equation,

$$\frac{\Delta a}{\Delta F} = \frac{\Delta a'}{\Delta F'} = \mu \tag{2}$$

where μ is a constant. But by the nature of the construction

$$\Delta F = F - f$$

$$\Delta a = a - A$$

Equation (2) then becomes

$$a - A = \mu(F - f) \tag{3}$$

Substitution of equation (1) into equation (3) gives

$$\frac{a}{f} = \frac{\mu}{\alpha}\frac{F}{A} + \frac{(1 - \alpha\mu)}{\alpha} \tag{4}$$

The air-fuel ratio at point S is therefore a straight-line function of the fuel-air ratio at point R.

In the rich-mixture region, the power (or at constant speed, the imep) developed by an internal-combustion engine is roughly proportional to the rate of air induction. Hence, the line QR is approximately representative of a constant-power curve. Similarly, in the lean-mixture region the power developed is roughly proportional to the rate of fuel induction; the line QS approximately represents a constant-power curve. Points S and R therefore represent engine operation at about the same power output. (These approximations tend to give increasingly erroneous results as the limits of combustion are approached.)

When equation (4) is applied to knock-limited or preignition-limited engine data, the air-fuel ratio at lean mixtures is plotted against the fuel-air ratio at rich mixtures at corresponding power outputs.

RESULTS AND DISCUSSION

In order to illustrate the correlation, knock-limited performance data taken from references 4 and 5 are plotted in figure 1. These data were selected merely because the performance curves extended to quite low fuel-air ratios. No attempt was made to ascertain whether the charts of knock-limited air flow against fuel flow gave straight lines, but a visual inspection was made of the curves of knock-limited indicated mean effective pressure against fuel-air ratio to make sure they appeared normal. The analysis was also checked in terms of preignition-limited data (from reference 3), which are presented in figure 2.

In the preparation of figures 1 and 2, the air-fuel ratio at lean mixtures was plotted against the fuel-air ratio at rich mixtures for identical values of the knock-limited or preignition-limited indicated mean effective pressure on each side of the minimum indicated-mean-effective-pressure point. The data points shown were taken from the faired curves of the references at the specific indicated-mean-effective-pressure values indicated. The value of α was then chosen as the fuel-air ratio at the minimum indicated mean effective pressure and μ was so adjusted that the best straight line could be drawn through the plotted points. The resulting straight lines are shown on the figures.

An inspection of figure 1 indicates that the method applies for the data presented at fuel-air ratios below about 0.085. Above this value the points tend to fall below and to the right of the straight line, which might be caused by the proximity of the data to the combustibility limits in the lean-mixture region. In general, it is impossible to attain as high power in the lean-mixture as in the rich-mixture region. In the worst case (fig. 1(c)) the deviation of the data from the correlation line amounted to about 5 percent on the fuel-air-ratio scale, or about half this amount when the deviation is distributed between the fuel-air-ratio and the air-fuel-ratio scales. Even when an internal coolant was injected (fig. 1(d)), the relation was nearly linear.

The preignition-limited data usually had a larger α value than the knock-limited data presented, which permitted including data at higher fuel-air ratios. Some tendency for the points to fall above and to the left of the correlation line is to be noted at the higher fuel-air ratios (particularly in figs. 2(b) and 2(c)), but this trend was not consistent. (See fig. 2(e).) In no case were the deviations of the preignition-limited points from the line more than 4 percent on the fuel-air-ratio scale.

The minimum hot-spot (preignition promoter) temperature required to produce preignition is known to be insensitive to fuel-air ratio and charge density. (See reference 6.) The hot-spot temperature, on the other hand, is expected to be dependent upon the heating and cooling capacities of the combustible mixture; and the effectiveness of these capacities is reflected in the observed variation of preignition-limited charge density with fuel-air ratio. Let the total cooling capacity of the excess air in the lean region and the "excess" fuel in the rich region per unit weight be represented by C_a and C_F, respectively. (These quantities must be regarded as covering the over-all cooling capacities; for instance, C_F includes the effects of latent heat of vaporization, of specific heat, and also of the excess fuel on the energy release from combustion.) In the notations of the sketch presented under ANALYSIS, the total cooling capacity of the excess air along the line QS should be approximately equal to the total cooling capacity of the excess fuel along the line QR; that is, $C_a \Delta a = C_F \Delta F$. If this expression is compared with equation (2), μ appears to be equal to the ratio C_F/C_a — provided that the assumptions are valid. For the data in figure 2, the observed values of μ varied from 11.2 to 15.7.

SUMMARY OF RESULTS

When the air-fuel ratio at lean mixtures was plotted against the fuel-air ratio at rich mixtures for identical values of knock-limited (or preignition-limited) indicated mean effective pressure on each side of the minimum indicated-mean-effective-pressure point, the data fell very close to a straight line in almost all of the cases investigated. The correlation obtained indicates that the influential variables controlling the knock-limited (or preignition-limited) performance of a fuel in the lean-mixture and rich-mixture branches of the performance curves are related.

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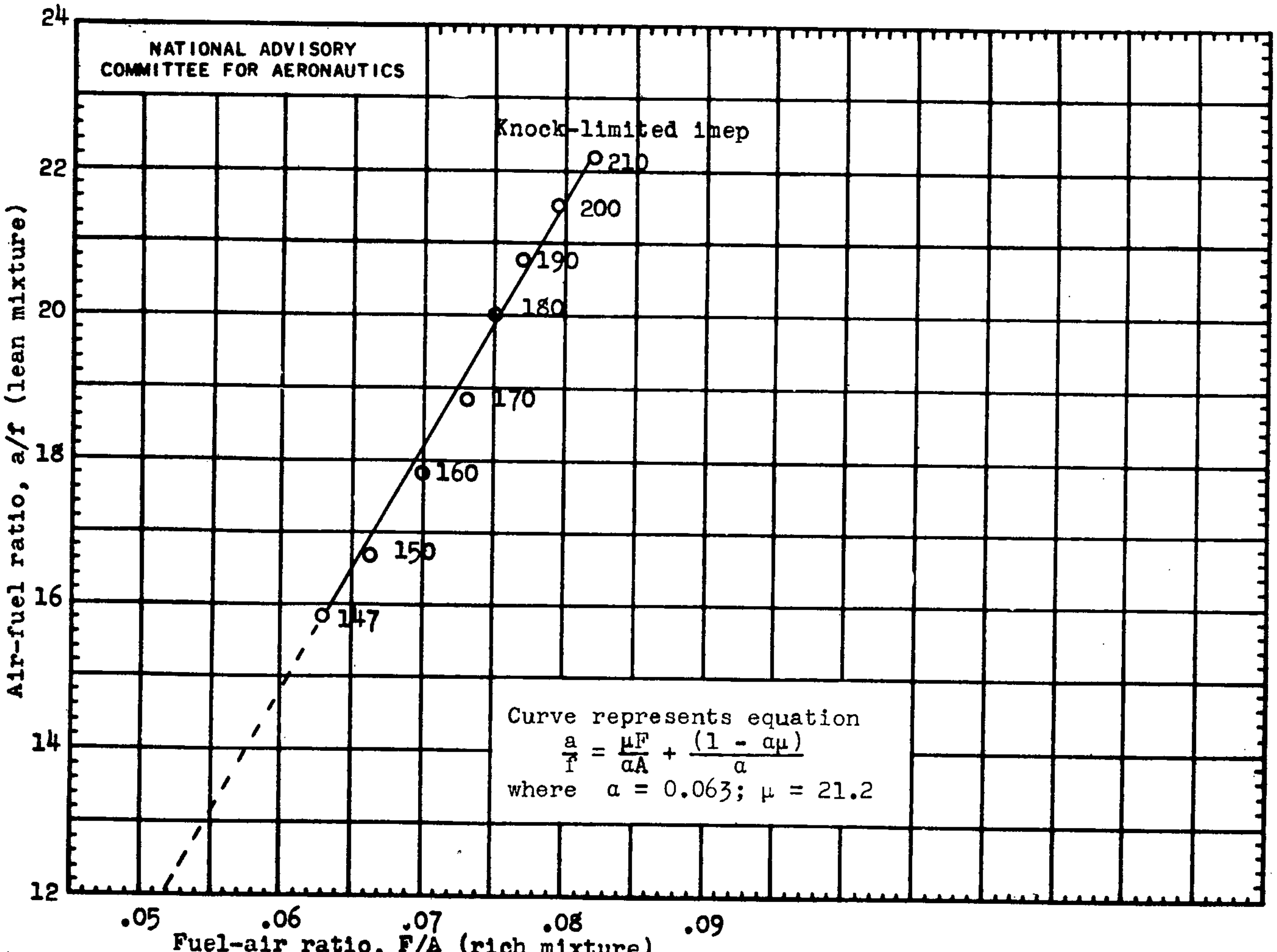
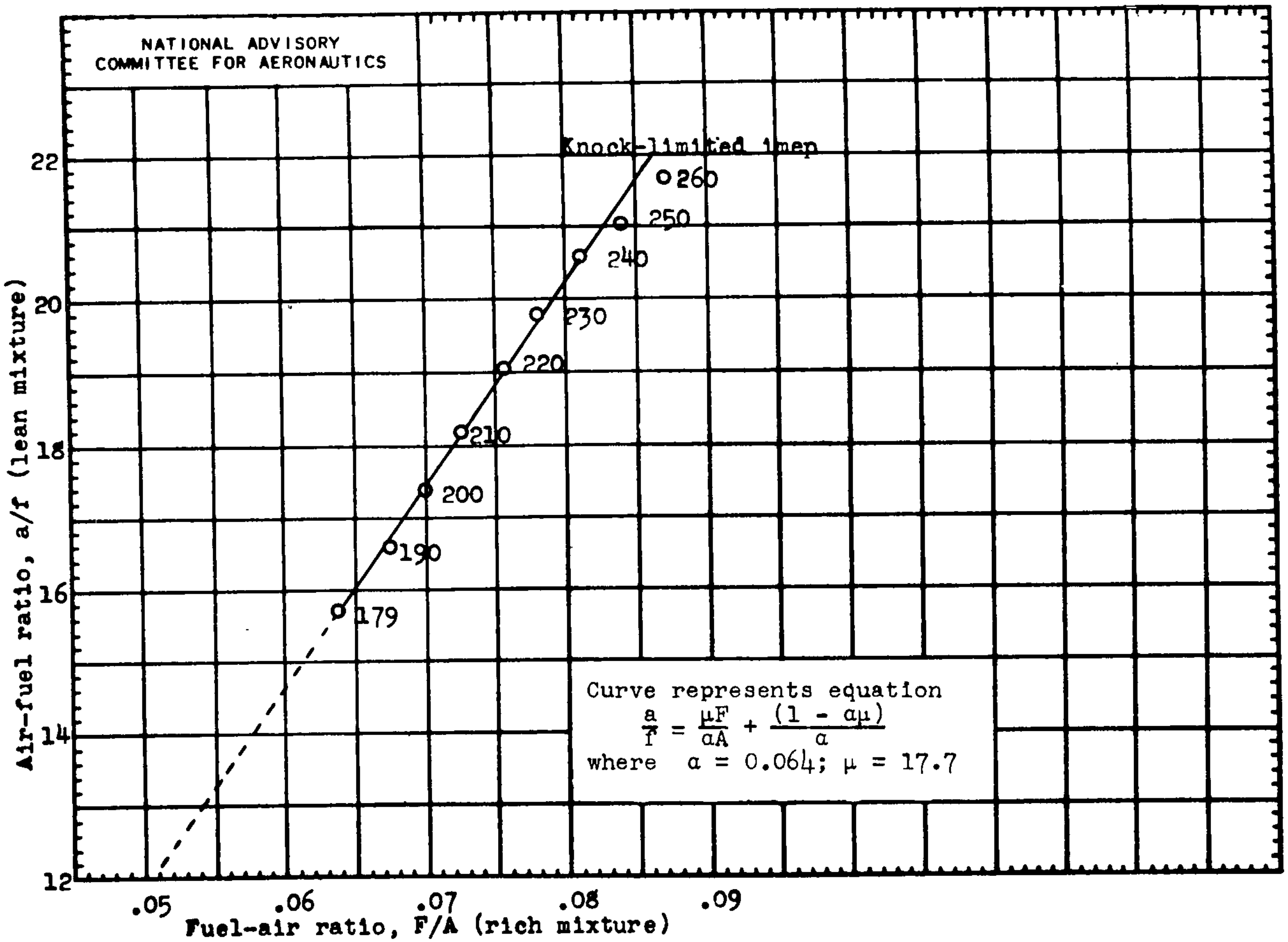


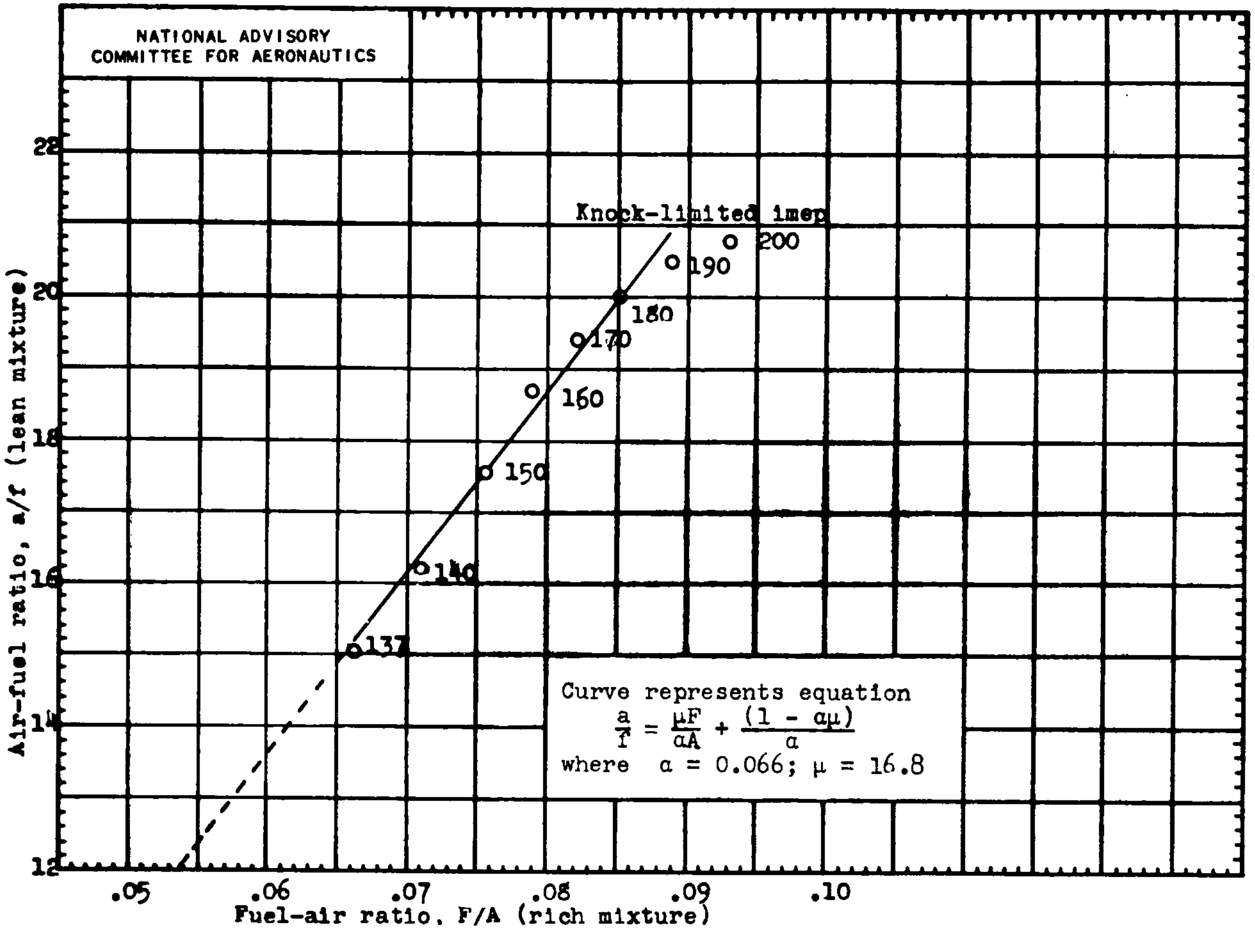
(a) AN-F-28, Amendment-2, fuel. (Data from reference 4, fig. 1(b).)

Figure 1. - Correlation of lean-mixture air-fuel ratio with rich-mixture fuel-air ratio at corresponding knock-limited indicated mean effective pressure. CFR engine; four-hole cylinder, dual ignition; spark advance, 30° B.T.C.; compression ratio, 7.0; inlet-air temperature, 250° F; coolant temperature, 250° F; engine speed, 2500 rpm.



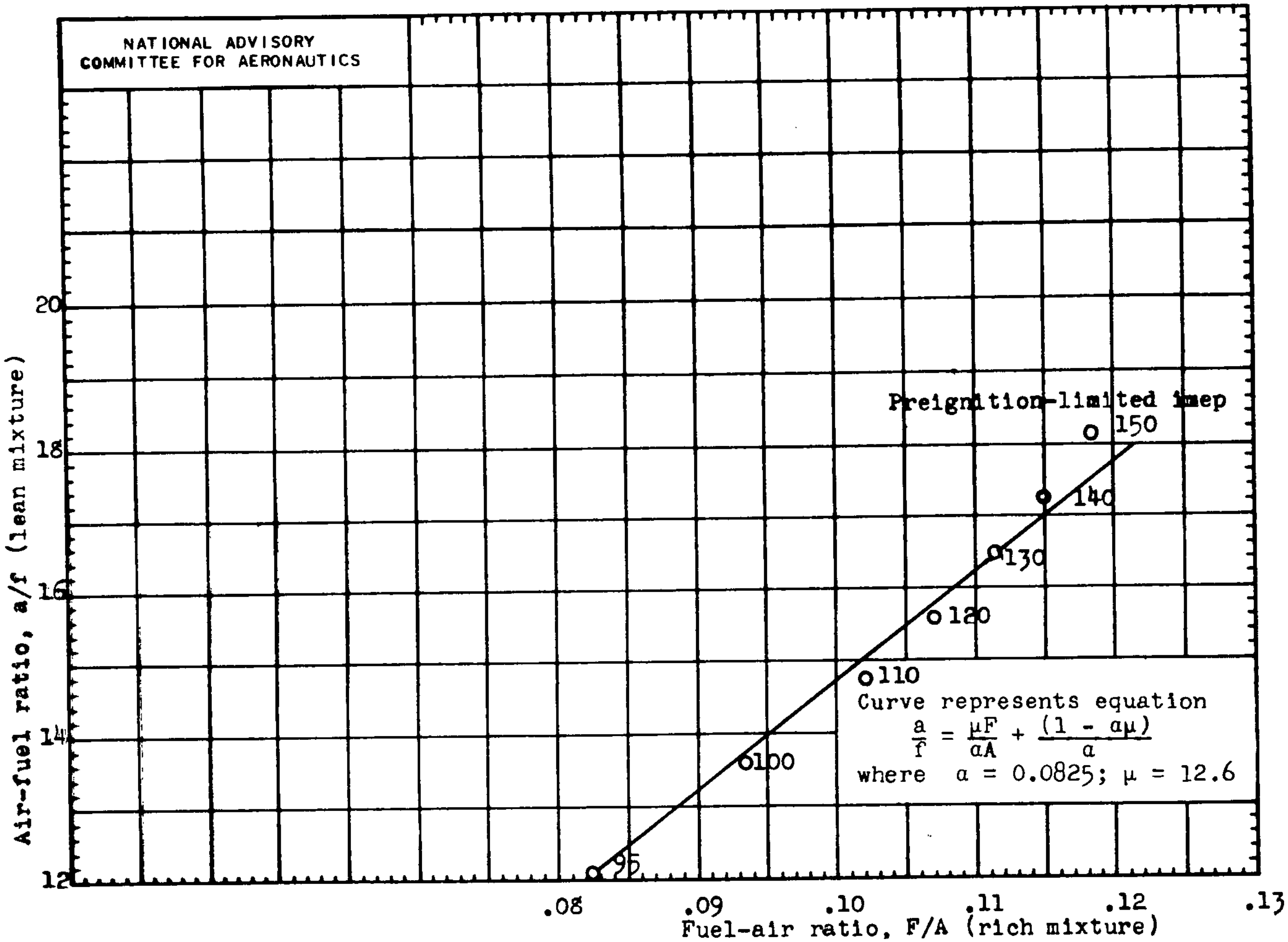
(b) 10 percent (by vol.) methyl tert-butyl ether, 90 percent AN-F-28, Amendment-2, fuel. (Data from reference 4, fig. 1(b).)

Figure 1. - Continued. Correlation of lean-mixture air-fuel ratio with rich-mixture fuel-air ratio at corresponding knock-limited indicated mean effective pressure. CFR engine; four-hole cylinder, dual ignition; spark advance, 30° B.T.C.; compression ratio, 7.0; inlet-air temperature, 250° F; coolant temperature, 250° F; engine speed, 2500 rpm.



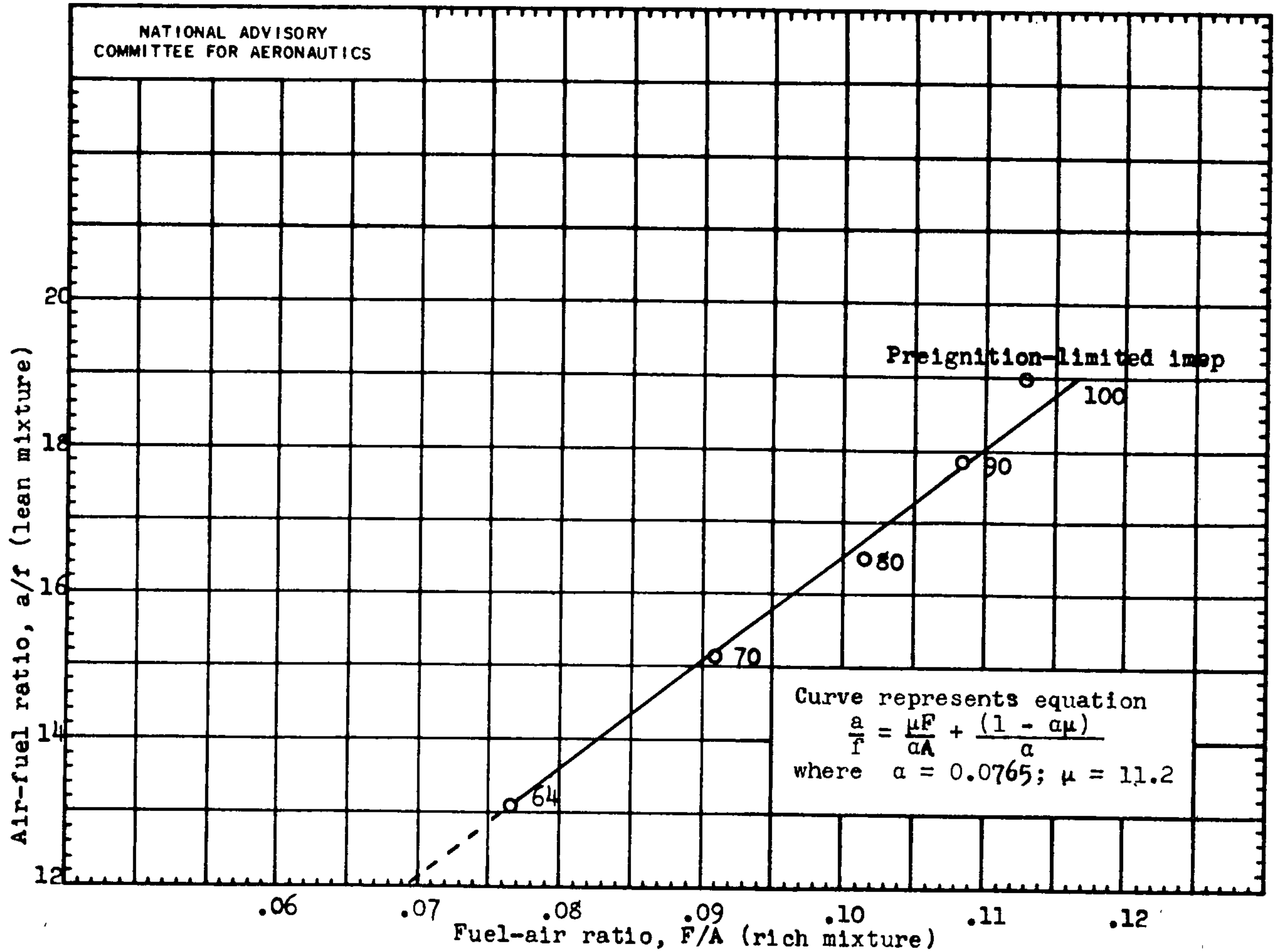
(c) 10 percent (by vol.) mesityl oxide, 90 percent AN-F-28, Amendment-2, fuel. (Data from reference 4, fig. 1(b).)

Figure 1. - Continued. Correlation of lean-mixture air-fuel ratio with rich-mixture fuel-air ratio at corresponding knock-limited indicated mean effective pressure. CFR engine; four-hole cylinder, dual ignition; spark advance, 30° B.T.C.; compression ratio, 7.0; inlet-air temperature, 250° F; coolant temperature, 250° F; engine speed, 2500 rpm.



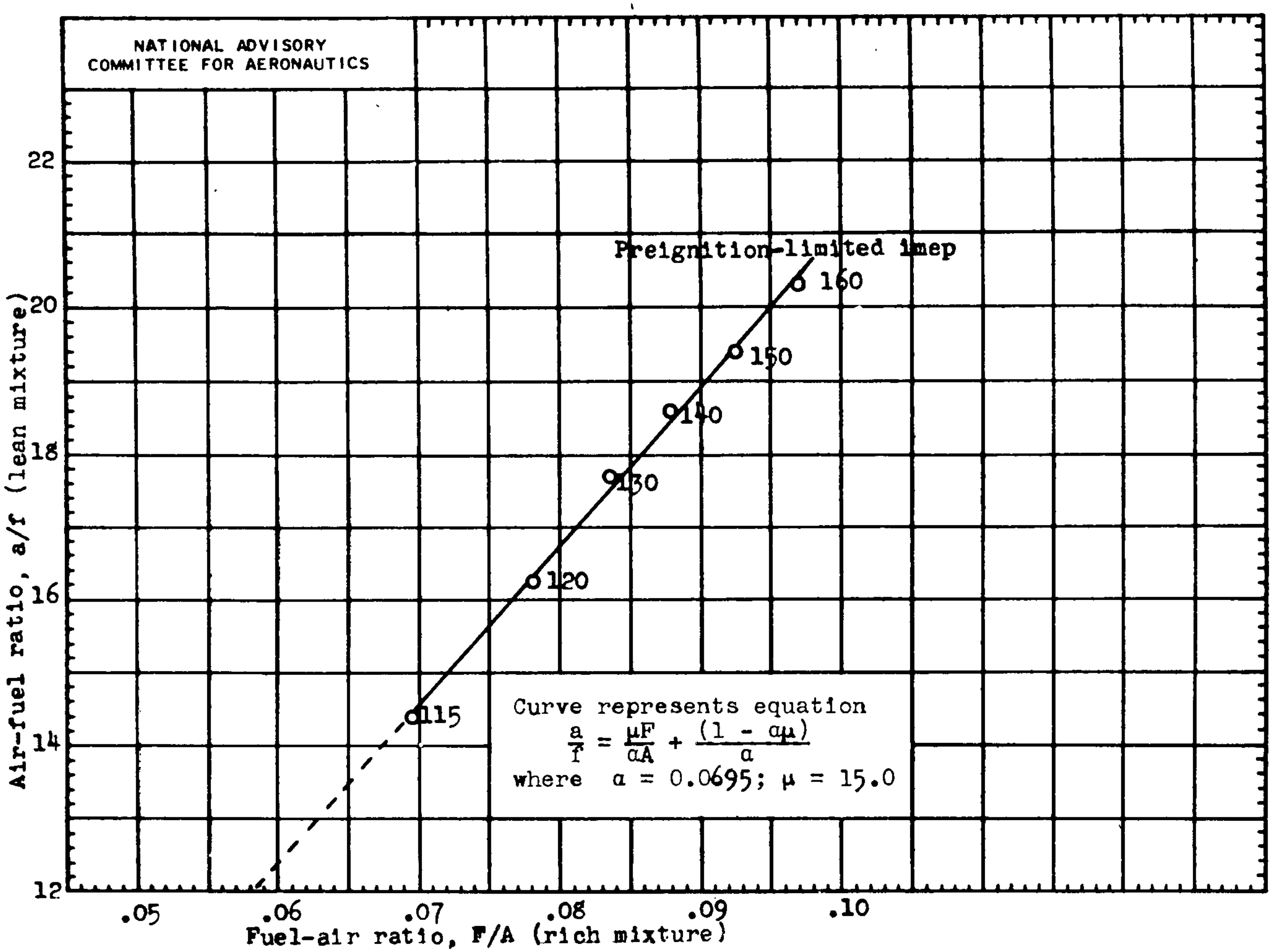
(b) Benzene. (Data from reference 3, fig. 5.)

Figure 2. - Continued. Correlation of lean-mixture air-fuel ratio with rich-mixture fuel-air ratio at corresponding preignition-limited indicated mean effective pressure. CFR engine; 180° shrouded intake valve; four-hole cylinder, dual ignition; spark advance, 20° B.T.C.; compression ratio, 7.0; inlet-air temperature, 225° F; coolant temperature, 250° F; engine speed, 1800 rpm.



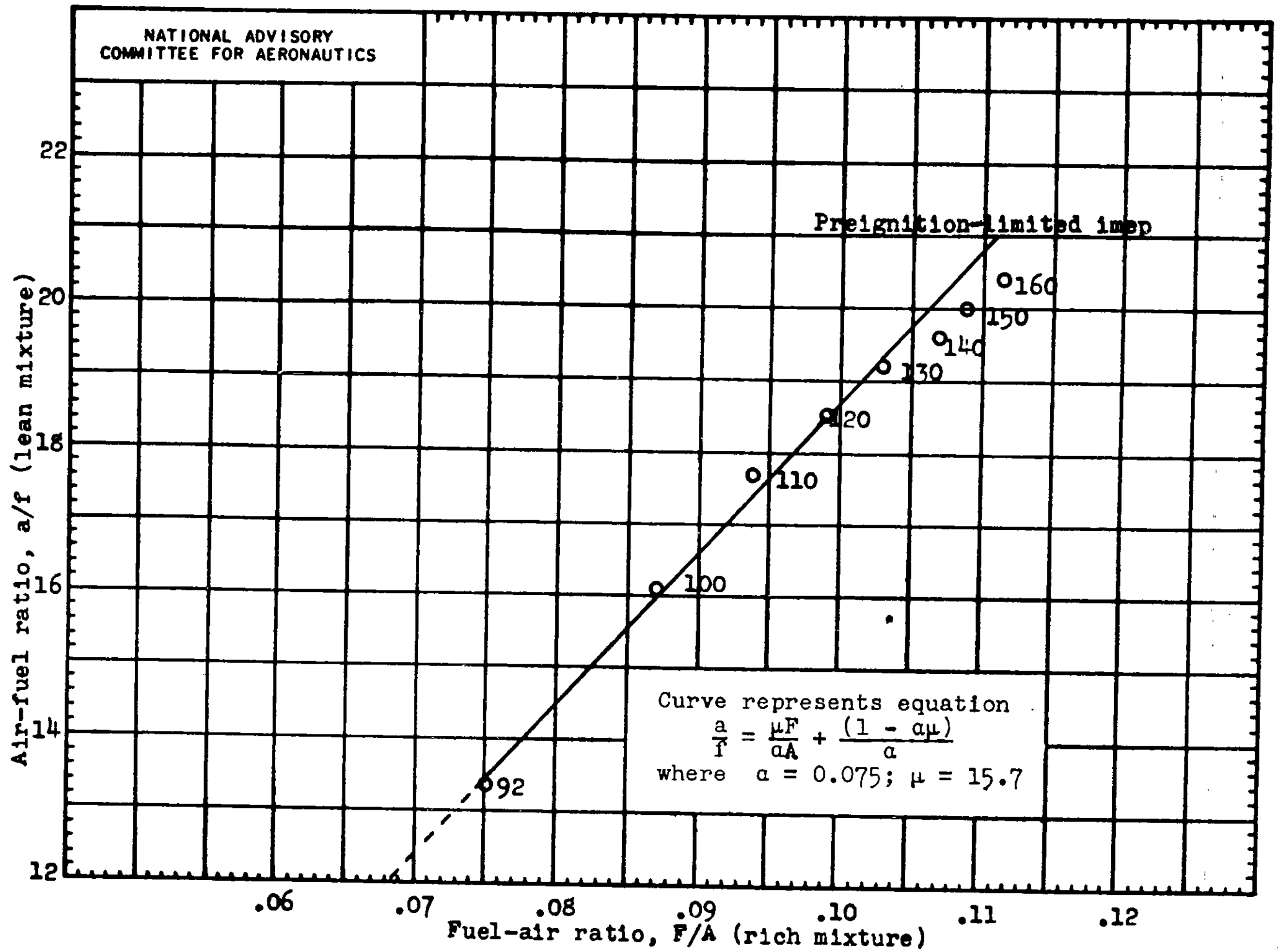
(c) Diisobutylene. (Data from reference 3, fig. 5.)

Figure 2. - Continued. Correlation of lean-mixture air-fuel ratio with rich-mixture fuel-air ratio at corresponding preignition-limited indicated mean effective pressure. CFR engine; 180° shrouded intake valve; four-hole cylinder, dual ignition; spark advance, 20° B.T.C.; compression ratio, 7.0; inlet-air temperature, 225° F; coolant temperature, 250° F; engine speed, 1800 rpm.



(d) 28-R, batch 1. (Data from reference 3, fig. 6.)

Figure 2. - Continued. Correlation of lean-mixture air-fuel ratio with rich-mixture fuel-air ratio at corresponding preignition-limited indicated mean effective pressure. CFR engine; 180° shrouded intake valve; four-hole cylinder, dual ignition; spark advance, 20° B.T.C.; compression ratio, 7.0; inlet-air temperature, 225° F; coolant temperature, 250° F; engine speed, 1800 rpm.



(e) Triptane. (Data from reference 3, fig. 6.)

Figure 2. - Concluded. Correlation of lean-mixture air-fuel ratio with rich-mixture fuel-air ratio at corresponding preignition-limited indicated mean effective pressure. CFR engine; 180° shrouded intake valve; four-hole cylinder, dual ignition; spark advance, 20° B.T.C.; compression ratio, 7.0; inlet-air temperature, 225° F; coolant temperature, 250° F; engine speed, 1800 rpm.